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ACCIDENTAL HYPOTHERMIA: AN EXPERIMENTAL STUDY OF PRACTICAL REWA--ETC(U)

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ACCIDENTAL HYPOTHERMIA:

AN EXPERIMENTAL STUDY OF PRACTICAL REWARMING METHODS

MAY 1976

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16. Abstract

Five rewarming techniques, appropriate for first-aid use in the non-hospital setting, were applied to each of nine subjects whose body temperatures had been lowered to 35°C in a stirred tank of 7.5°C water. The rewarming techniques were as follows: (a) Shivering, (b) Inhalation of heated, water-saturated oxygen, (c) Placement of heating pads over areas of high heat transfer, (d) Combination of methods (b) and (c), (e) Hot whirlpool bath. Inhalation of heated, water-saturated oxygen was significantly better than the shivering control in terms of minimizing temperature "afterdrop", and is therefore preferred over the other techniques as it avoids the physiological hazards associated with the peripheral vasodilation which accompanies external rewarming.

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METRIC CONVERSION FACTORS

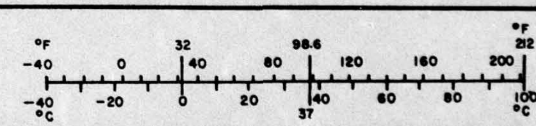
Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



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ABSTRACT

Five rewarming techniques, appropriate for first-aid use in the non-hospital setting, were applied to each of nine subjects whose body temperatures had been lowered to 35°C in a stirred tank of 7.5°C water. The rewarming techniques were as follows: (a) Shivering, (b) Inhalation of heated, water saturated oxygen, (c) Placement of heating pads over areas of high heat transfer, (d) Combination of methods (b) and (c), (e) Hot whirlpool bath. Inhalation of heated, water saturated oxygen was significantly better than the shivering control in terms of minimizing temperature "afterdrop", and is therefore preferred over the other techniques as it avoids the physiological hazards associated with the peripheral vasodilation which accompanies external rewarming.

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INTRODUCTION

Accidental hypothermia in man is a common, but serious problem in cold air and water environments. The rapid rate of cooling which occurs in cold water immersion (11) and in mountain accidents (9, 30) can readily progress to a medical emergency. Hence immediate recognition and therapy of this condition are necessary to overcome its high mortality (5, 28).

Since the United States Coast Guard has primary responsibility for search and rescue in United States territorial waters, it has a profound interest in developing more effective first-aid procedures for use aboard its rescue vehicles. Because hypothermia fatalities have occasionally occurred even after removal of the victim from his cold environment (29, 39) organizations involved in the recovery of hypothermia victims should have the capacity for definitive first-aid treatment. To date, however, there have been no well-controlled studies to assess the efficacy of various practical methods of on-site therapy in accidental hypothermia. To this end the United States Coast Guard has contracted the present experiment.

In regards to the treatment of hypothermia, many current articles (8, 9, 18), medical texts (2), and military survival publications (7, 39), recommend rapid peripheral rewarming as the treatment of first choice. Indeed, this has been shown to be effective even in the profoundly hypothermic victim (1). Many modalities are used to accomplish this, including immersion in hot water baths, wrapping in electric blankets, application of heated objects to the skin surface (3), and recently, circulation of warm water through special garments fitted to the victim (40). These methods are all effective in treatment of rapid-onset hypothermia,

but certain physiological problems may arise with active, peripheral rewarming of the slow-onset, unconscious, severely hypothermic victim. The well-described "afterdrop" of the core body temperature following removal of the cold stress can be increased in magnitude by peripheral rewarming. This occurs through vasodilation in the cold periphery and subsequent return of cooled blood to the body core, further chilling the myocardium (3) and potentiating the possibility of ventricular fibrillation (1, 19, 3). Furthermore, in hypothermia of long duration, in which intravascular volume is decreased secondary to fluid shifts, rapid rewarming may precipitate hypovolemic shock as peripheral vasodilation further diminishes central blood volume (19, 3). To obviate these problems, some authorities (19, 38) recommend rapid rewarming for rapid-onset hypothermia, and slow rewarming for slow-onset hypothermia. The difficulty in many accident situations of ascertaining the degree of hypothermia and its duration, complicates the decision of which type of therapy to apply, at a time when delay decreases the chance of successful resuscitation.

Theoretically, core rewarming of the hypothermic victim avoids the physiological hazards mentioned above, through delivery of heat directly to the central circulation and tissues, leaving the limbs and peripheral tissues to warm more slowly. Several core rewarming methods have been used including extracorporeal circulation (6, 37), warm peritoneal dialysis (20), direct warming of the heart after thoracotomy (22), and endotracheal administration of warm air alone (34) and in combination with heated, intravenous fluids (35).

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Recently, Lloyd (23) has described a means of core rewarming through the airway using warmed, saturated oxygen. He presents case histories (23, 24, 25) showing its effectiveness in the hospital treatment of hypothermic patients, and he describes a portable apparatus, based on this principle, for first-aid use (24). In addition, several other recent reports in the medical literature have recommended airway rewarming as an adjunct to hypothermia therapy (36, 21, 13). Inhalation rewarming has also been used with good results by certain mountain rescue organizations, and on several recent occasions hypothermia victims have been successfully treated on the mountainside with a portable rewarming device (33). Experiments on hypothermic dogs have shown that inhalation rewarming can provide sufficient calories to rewarm the animal, and the technique provides a significant elevation of aortic blood temperature (16). Finally, an experimental study on human volunteers, jointly sponsored by the United States Coast Guard and the University of Victoria, Victoria, British Columbia demonstrated that there was no significant difference in the magnitude of tympanic or rectal temperature afterdrops between inhalation rewarming and rewarming by immersion in a hot bath (13)

The purpose of the present experiment was to examine the effectiveness of several rewarming techniques applicable to the first-aid treatment of hypothermia. Five methods of rewarming were studied:

(1) core rewarming by inhalation of heated, saturated oxygen;

(2) peripheral rewarming by application of heating pads to the neck, lateral thorax, and groin;

(3) rewarming by a combination of methods (1) and (2);

(4) passive rewarming by shivering alone;

(5) peripheral rewarming in a hot whirlpool bath.

(8)

Inhalation rewarming and water bath rewarming were studies both to confirm the results of the previous experiment (13) and to compare the effectiveness of each technique with the other three methods of rewarming. The sites for heating pad rewarming were selected because these areas have been shown thermographically (10) to have a high rate of heat transfer with the core, and because the limited surface area being heated would minimize the afterdrop usually associated with peripheral rewarming. Passive rewarming by shivering thermogenesis served as a control for the other methods, since each of the other four techniques had varying degrees of associated shivering. In addition to these five rewarming methods, a separate study, using a smaller number of subjects, tested the efficacy of peripheral rewarming by body contact with normothermic volunteers. This latter technique has been often recommended when no other active means of rewarming are available (39, 1).

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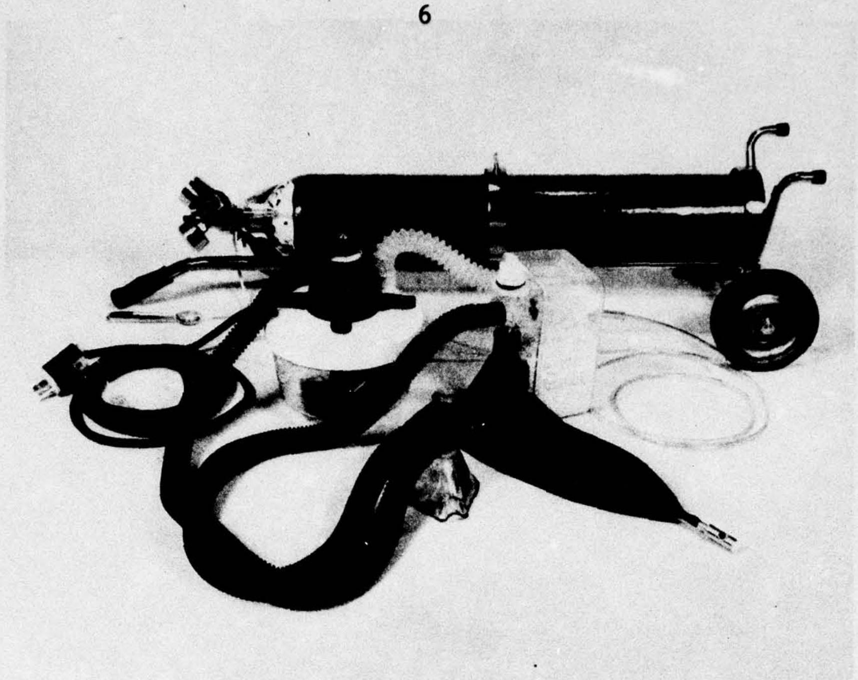

Figure 1. Bennet Cascade Humidifier, and anesthesia circuit for delivery of heated saturated O_2.

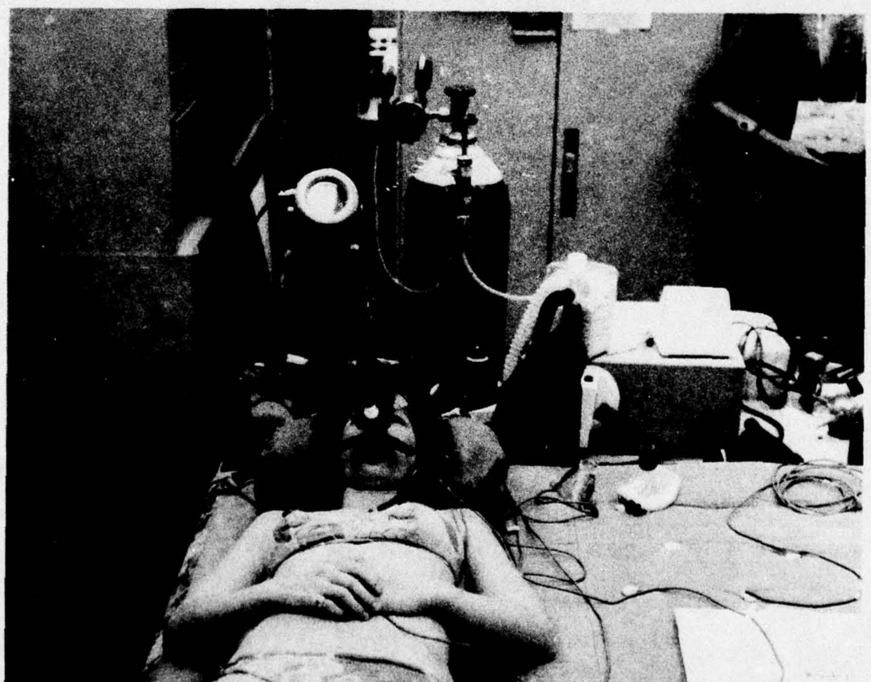

Figure 2. Subject receiving heated, water saturated O_2.

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Table 1. Physical Characteristics of Subjects.

Subject	Sex	Height (in.)	Weight (lbs.)	Age	Body Density (gm./ml.)	% Fat
S.A.	M	70.0	182	28	1.071	12.5
D.B.	M	68.5	152	20	1.084	7.6
M.C.	F	68.0	140	21	1.045	23.2
C.F.	F	64.5	125	23	1.056	18.6
B.L.	M	68.0	145	20	1.083	7.8
J.M.	F	62.0	116	23	1.054	19.3
G.M.	M	71.0	190	30	1.083	7.9
W.R.	M	72.5	162	27	1.082	9.2
T.A.	M	69.0	150	24	1.079	9.1

MATERIALS AND METHODS

Immersions took place in a laboratory setting, in order that there would be no variability in water or air conditions. The immersion posture for subjects was standardized so that the neck and head remained clear of the water while the shoulders and the remainder of the body were completely immersed. Subjects made no voluntary movements and maintained their position by standing on an insulated stepladder which was immersed in the tank. The temperature of the constantly stirred water in the tank was held at 7.5°C which is typical of ocean temperatures in the Pacific Northwest.

Nine healthy subjects, three female and six male, all of whom were athletically active, volunteered to participate in the study and undergo a minimum of five immersions. Prior to participation they previously had to satisfy rigorous medical criteria described previously (13). Personal characteristics of the subjects are shown in Table 1.

Continuous temperature monitoring took place throughout the pre-immersion, immersion and rewarming phases of the experiment. Core temperatures were recorded as follows: fine, padded thermocouples were placed gently against the tympanum of both ears, and the auditory meatus of each ear was sealed with a soft wax plug. Rectal temperature was monitored with a thermistor inserted 15 centimeters beyond the anus. Skin temperatures were monitored by thermistors protected from the water by means of waterproof tape. The skin thermistors were placed on the forehead, epigastrium and left foot of each subject.

During every immersion the subjects were under constant surveillance by a physician. As in previous studies (13, 12) immersions were terminated when a subject's rectal temperature reached 35°C or prior to this, on

(12)

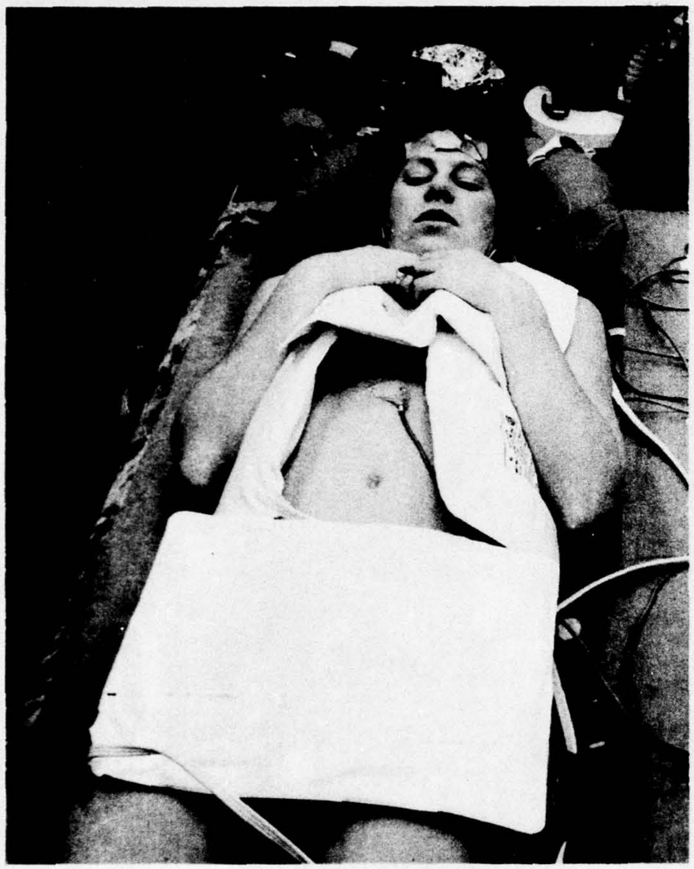

Figure 3. Heating pads

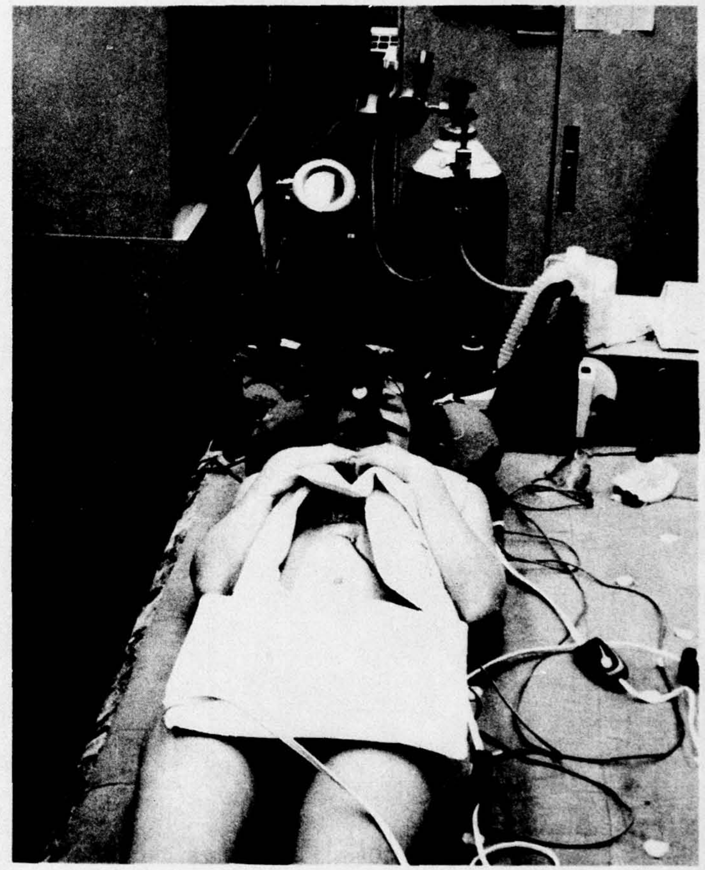

Figure 4. Heated, water saturated O_2 in conjuction with heating pads

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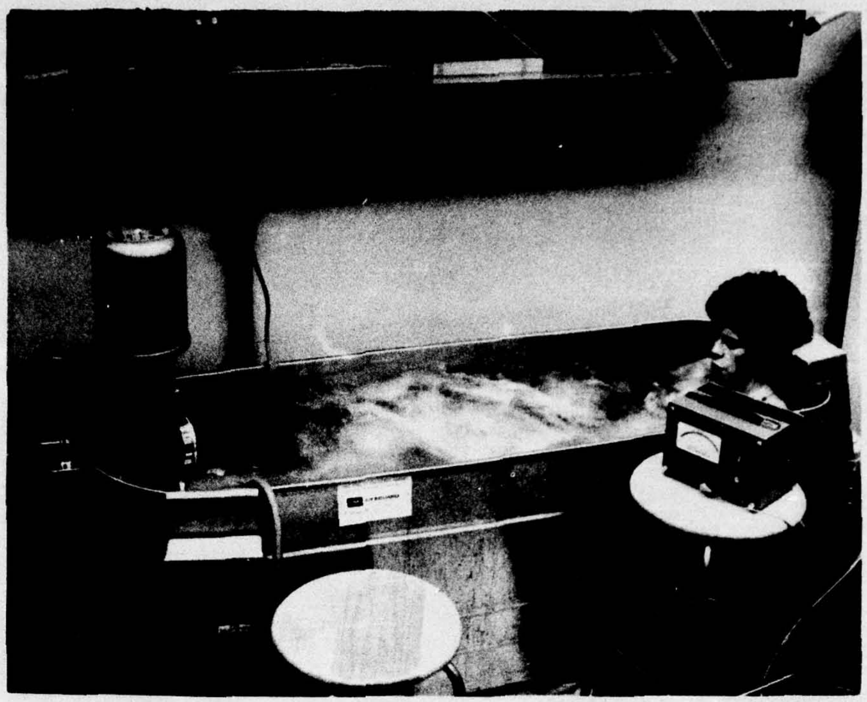

Figure 5. Whirlpool bath

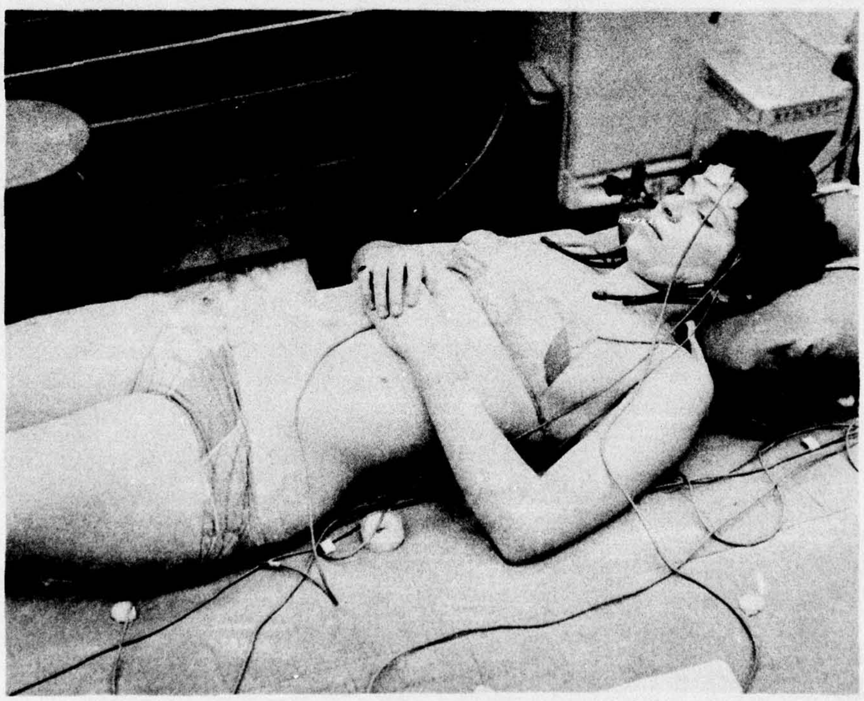

Figure 6. Shivering control

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(14)

request of the subject or on the advice of the attending physician. However, all subjects were able to remain immersed until their rectal temperature reached 35°C. During the rewarming phase of the experiment, when core temperatures reached their lowest point, continuous E.C.G. monitoring took place, in addition to the temperature recording and physician surveillance. Emergency resuscitation equipment was on hand at all times, and included a defibrillator, oxygen bag-mask equipment for ventilation and standard pharmacologic agents.

Rewarming Procedures

All subjects were helped from the tank on completion of their immersion and lightly dried off with towels. Within 90 seconds, subjects were placed supine on an adjacent mattress on which they lay uncovered throughout the rewarming period. Laboratory temperature was held constant at 22°C. An exception to the above procedures was the rewarm in the whirlpool bath where subjects were transferred immediately from the cooling tank into the rewarming bath.

1. Heated Water Saturated O_2

Heated saturated O_2 was delivered to the subject by means of a Dryden disposable anesthesia circuit consisting of a breathing bag, hoses, soda-lime absorber, one-way valves, mask and oxygen source in circuit with a Bennet cascade humidifier in the inspiratory limb. The circuit was modified by C.W. Bollinger and R.D. Chaney for use as a rewarming device. Oxygen was bubbled through the water and delivered to the subject via a mouthpiece or loosely fitting face mask. (Figures 1 and 2.)

The flow rate of oxygen was adjusted to keep the reservoir bag expanded. This required flows of 4 to 12 L/min. for the initial 5 to 10 minutes. As

profound shivering subsided, oxygen flow rates were decreased to 3 to 5 L/min. Temperature at the mask was maintained in all subjects at 43-48°C. This was accomplished by adjusting the temperature setting of the Bennet cascade humidifier.

With the Dryden disposable semi-closed anesthesia circuit in the system, exhaled gases can either pass into the atmosphere or mingle with the fresh heated, saturated oxygen resulting in partial rebreathing. A soda-lime absorber is added to the system to provide for removal of carbon dioxide. The reservoir bag provides for assisted respirations. Loss of heat and moisture is thus minimized by the re-cycling principle.

2. Heating Pads

Four thermostatically controlled heating pads were placed on the neck, lateral thorax and groin. The heating pads were held tightly in place and a skin/pad interface temperate of approximately 50°C maintained. (See Figure 3.)

3. Heated, Water Saturated O_2 and Heating Pads

Combination of methods (1) and (2). (See Figure 4.)

4. Whirlpool Bath

Subjects stepped from the cooling tank into the whirlpool bath in which the water temperature was 26.5°C. Over a period of 10 minutes the temperature was gradually increased to 43.5°C. (See Figure 5.)

5. Shivering

Subjects lay supine as described, and allowed shivering thermogenesis to take place. This rewarming technique was terminated and the subject transferred to the whirlpool bath, where spontaneous thermogenesis was unable to quickly reverse the afterdrop in temperature or on the advice of the presiding physician. (See Figure 6.)

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Table 2. Normothermic Control. Tympanic and rectal temperature responses to heated, water saturated O_2.

Subject		Start	Finish	Change
D.B.	T_T	36.90	36.85	-.05
	T_R	37.70	37.60	-.10
T.A.	T_T	36.60	36.60	0
	T_R	36.95	36.92	-.03
C.W.	T_T	36.70	36.60	-.10
	T_R	37.02	36.90	-.12
S.A.	T_T	36.70	36.74	+.04
	T_R	37.22	37.29	+.07
J.M.	T_T	36.60	36.70	+.10
	T_R	37.50	37.62	+.12
C.F.	T_T	36.40	36.50	+.10
	T_R	36.55	36.30	-.25
M.C.	T_T	36.70	36.95	+.25
	T_R	37.50	37.45	-.05

Heated Oxygen

$\bar{Y} \Delta T_T = +0.05 \pm 0.15$

$\bar{Y} \Delta T_R = -0.05 \pm 0.12$

(17)

Table 3. Normothermic Control. Tympanic and rectal temperature responses to heating pads placed on areas of high heat transfer.

Subject		Start		Finish		Change	
D.B.	T_T	36.70		36.75		+.05	
	T_R		37.55		37.50		-.05
T.A.	T_T	36.60		36.45		-.15	
	T_R		36.95		36.85		-.10
C.W.	T_T	36.65		36.65		0	
	T_R		36.90		36.80		-.10
S.A.	T_T	36.65		36.50		-.15	
	T_R		37.05		37.05		0
J.M.	T_T	36.62		36.59		-.03	
	T_R		37.63		37.40		-.23
C.F.	T_T	36.15		36.00		-.15	
	T_R		36.20		36.00		-.20
M.C.	T_T	36.65		36.60		-.05	
	T_R		37.37		37.23		-.14

<u>Heating Pads</u>

$$\bar{Y}\Delta T_T = -0.07 \pm 0.08$$

$$\bar{Y}\Delta T_R = -0.12 \pm 0.08$$

(18)

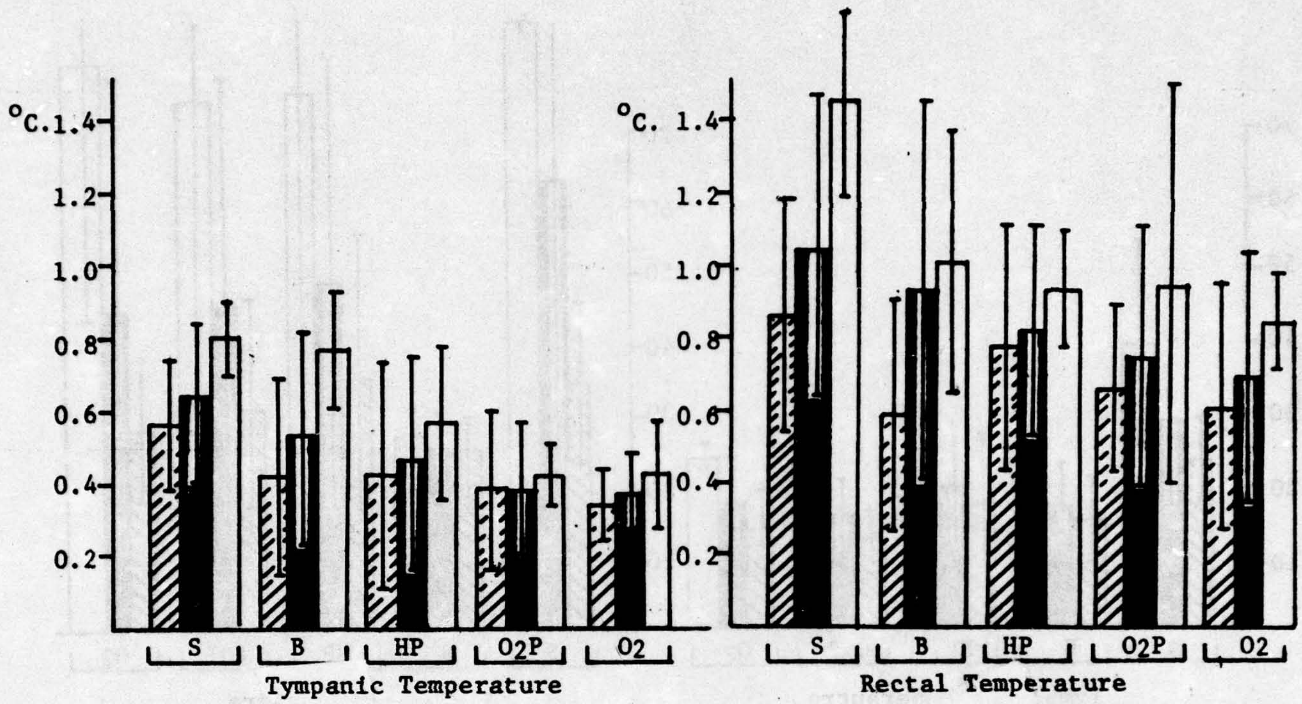

Figure 7. Tympanic and rectal temperature afterdrops.

Y ± SD for 6 "shiverers"

Y ± SD for all 9 subjects

Y ± SD for 3 "non-shiverers"

Key for rewarming techniques

S - Shivering

B - Whirlpool bath

HP - Heating pads

O_2P - Heated, water saturated O_2 and heating pads

O_2 - Heated, water saturated O_2

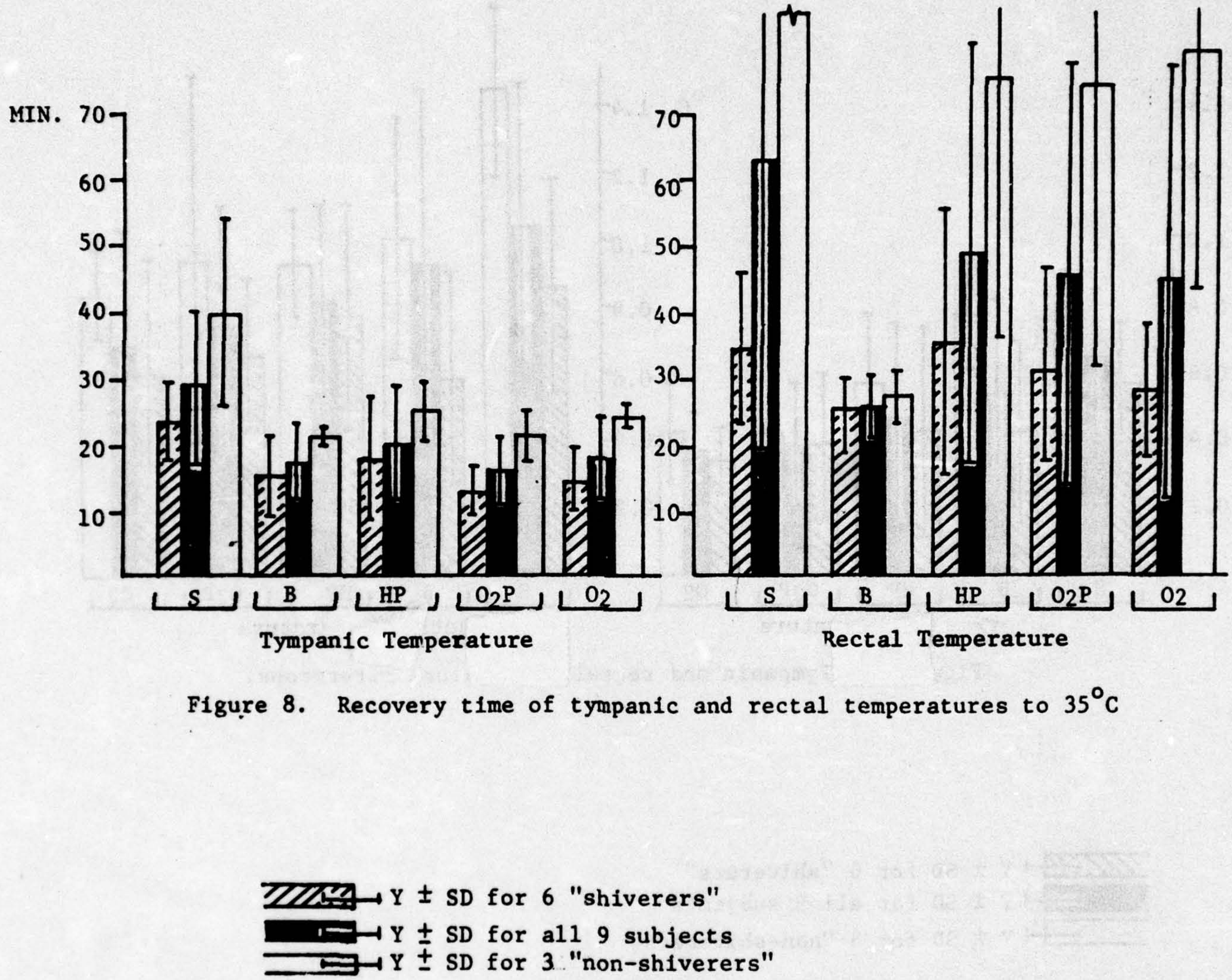

Figure 8. Recovery time of tympanic and rectal temperatures to 35°C

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Body to Body Rewarming Method

To test the efficacy of direct body to body contact as a rewarming technique, two subjects were rewarmed in the following manner. After a standard immersion during which the rectal temperature was lowered to 35°C the subjects were placed in a sleeping bag between two nomothermic unclothed volunteers.

Nomothermic Control

Comments in two recent papers suggested the tympanic temperature might be more responsive to local applications of heat than to changes in control temperatures (26,27). In order to control for the possibility that the heating pads and the heated, water saturated O_2 might have a direct heating effect on the tympanum, a pretest was run on the subjects in a nomothermic condition. Standard tympanic temperature recording techniques were followed, with thermocouples placed in each ear, and a thermistor in the rectum. Subjects clad in swim suits lay supine on foam mattresses for 10 minutes prior to the application of heat, temperature recording was continuous.

RESULTS

The results of the administration of heated water saturated O_2 and of the application of heat pads to the experimental group under nomothermic conditions are shown in Tables 2 and 3. The mean changes in tympanic temperature and rectal temperature with the heated water saturated O_2 were $+0.05^{o}C$ and $-0.05^{o}C$ respectively, showing no significance. Similarly, there was no significant temperature change with the application of heated pads although both tympanic and rectal temperatures showed a slight drop.

The histograms shown in Figures 7 and 8 indicate the mean responses of the subjects in terms of temperature change to the five rewarming parameters studied. The experimental group is presented in its entirety and is also split into two sub-groups, namely, those who were able to shiver themsevles warm, and those who were unable to reverse their falling temperature by shivering thermogenesis. The ability to produce heat by violent shivering can affect all rewarming parameters, hence the separate display of low heat producing subjects provides an interesting indication of the role of shivering in the various rewarming procedures.

Statistical analysis was applied only to the total group means, as the sub-groups were of too small an 'n' for statistical purposes. A 2 way analysis of variance (ANOVA) was applied to determine if statistically significant differences existed between the various rewarming techniques. Having established this, a paired comparisons test was applied to show where these differences lay, their magnitude, and the direction ı of the differences.

In examining the effectiveness of different rewarming techniques, one can look at the "afterdrop" (amount of temperature drop after leaving the cold water), or the time taken until temperature returns to a predetermined

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level. Since both measures are of interest both are included for analysis and discussion.

Figure 9 shows a typical series of cooling and rewarming curves of an individual subject in response to the five immersions and rewarmings. The "afterdrop" is visible after the termination of the immersions, and the time for recovery back to 35°C can be traced. To facilitate comparison of the rewarming curves, the graph is structured so that all curves intersect at the point where the subject was removed from the cooling tank, when rectal temperature reached 35°C. Graphical individual responses are shown in Appendix 3. The variability in responses to different rewarming techniques is clearly visible and in some cases can be related to variability in individual capacity for shivering thermogenesis.

In a test of paired comparisons, a degree of statistical significance of $P \leq 0.01$ is an acceptable measure to indicate differences between various treatments. However, as the test is two tailed, a $P \leq .005$ is generally desirable to show the direction of the difference. The majority of treatments did not yield this level of statistically measurable variability, but produced some strong trends from which inferences can be drawn.

Using a level of statistical significance of $\leq .005$ the only significant difference in "afterdrop" of rectal temperature was between the shivering treatment and the use of heated, saturated O_2. The mean "afterdrop" in rectal temperature for subjects, when shivering was the only means of heat production was slightly greater than 1.0°C, this compares with an "afterdrop" of 0.68°C when subjects received heated, saturated O_2. The mean "afterdrop" for O_2 combined with heating pads and heating pads alone, was within 0.2°C

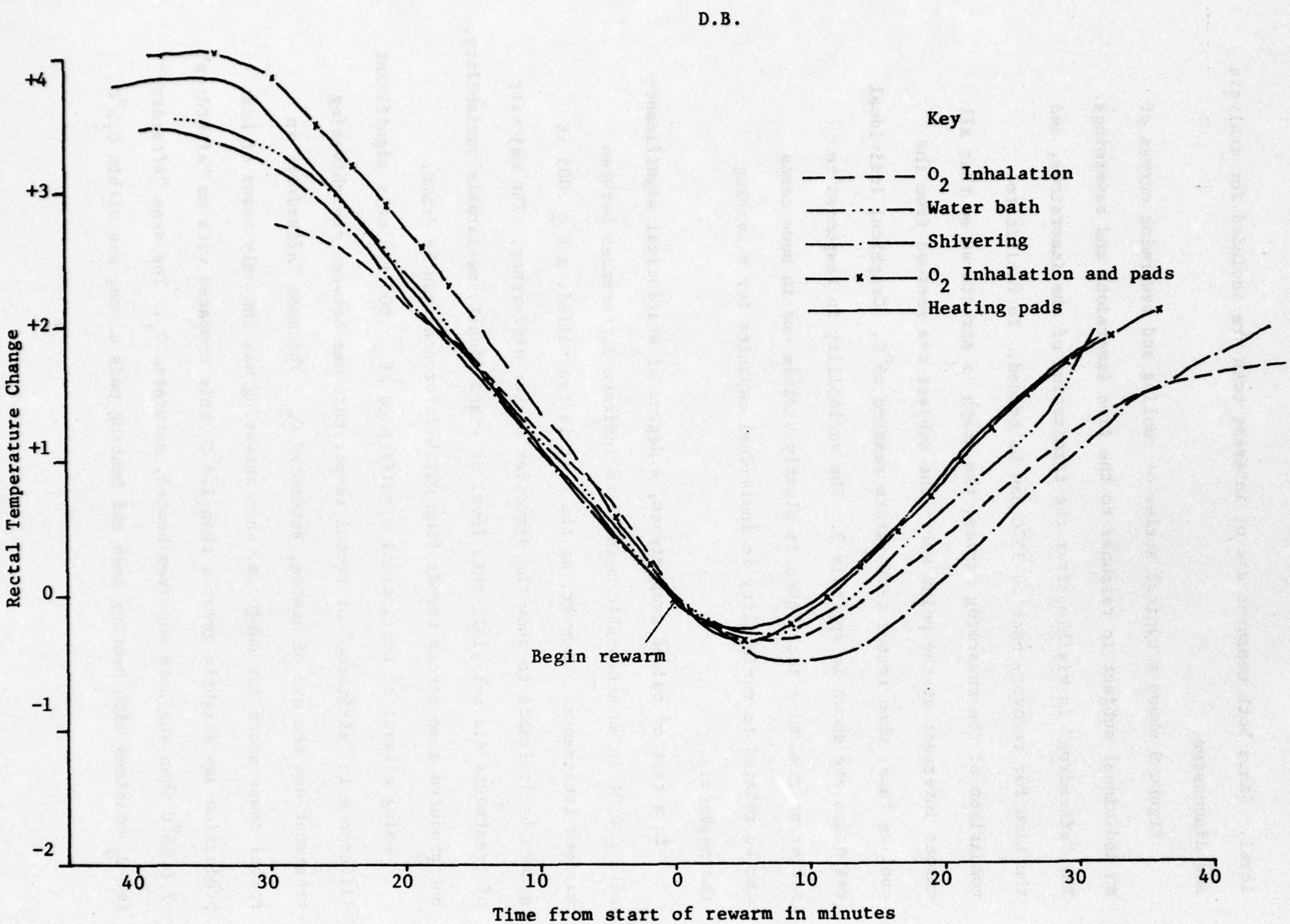

Figure 9. Cooling and rewarming curves of an individual subject, showing responses to five methods of rewarming.

(24)

D.B.

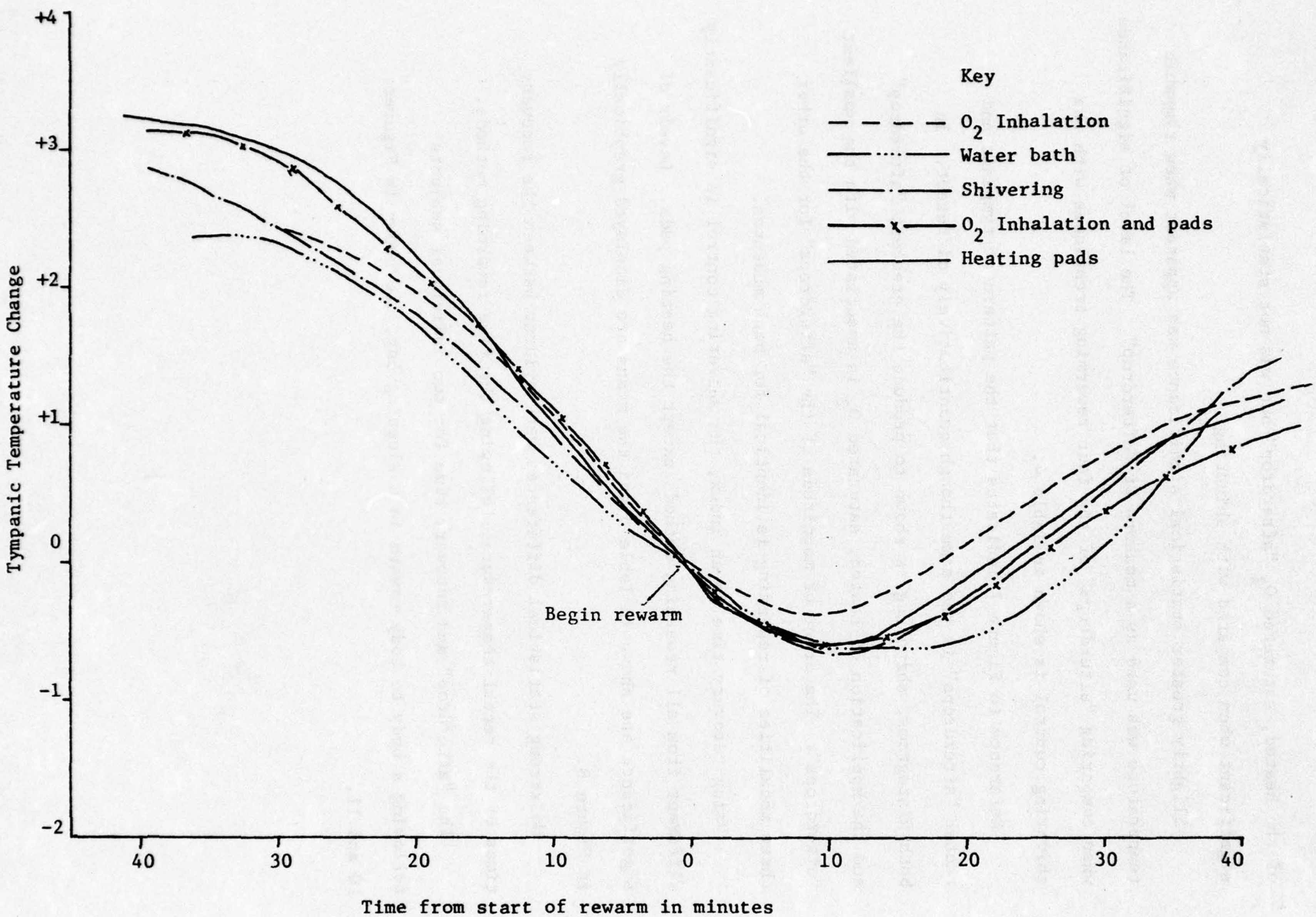

Figure 9a. Cooling and rewarming curves of an individual subject, showing responses to five methods of rewarming.

of the heated, saturated O_2 "afterdrop" but was not statistically significant when compared with shivering.

Slightly greater statistical significance was apparent when tympanic temperature was used as a measure of "afterdrop". The level of significance when comparing "afterdrops" of the four rewarming techniques with the shivering control is shown in Table 4.

Reference to Figure 7 indicates that the pattern of tympanic and rectal "afterdrops" is the same though quantitatively different. In both histograms, shivering is shown to produce the greatest "afterdrop" and the application of heated, saturated O_2 is associated with the smallest "afterdrops". The order of magnitude of the "afterdrops" for the other three modalities of rewarming is identical for both measures.

Using recovery time as an index, the shivering control is significantly different from all rewarming methods except the heating pads. Levels of significance are shown in Table 5 and the means are displayed graphically in Figure 8.

No strong statistical differences were evident between the recovery times of the rectal temperature, following the five rewarming methods.

The "afterdrop" and recovery time for two individual subjects following a body to body rewarm in a sleeping bag, are shown in Figures 10 and 11.

Table 4. Statistical comparison between the tympanic temperature "afterdrop" following the shivering control, and four rewarming techniques.

	Level of Significance
Shivering - Heated, saturated O_2	≤ 0.001
Shivering - Heated, saturated O_2 and heating pads	≤ 0.01
Shivering - Heating pads	≤ 0.25
Shivering - Hot whirlpool bath	No significant difference

Table 5. Comparison of recovery times for tympanic temperature showing level of significance of the differences between shivering and other rewarming modalities.

	Level of Significance
Shivering - Heated, water saturated O_2	≤ 0.005
Shivering - Heated, water saturated O_2 and heating pads	≤ 0.005
Shivering - Heating pads	≤ 0.025
Shivering - Whirlpool bath	≤ 0.005

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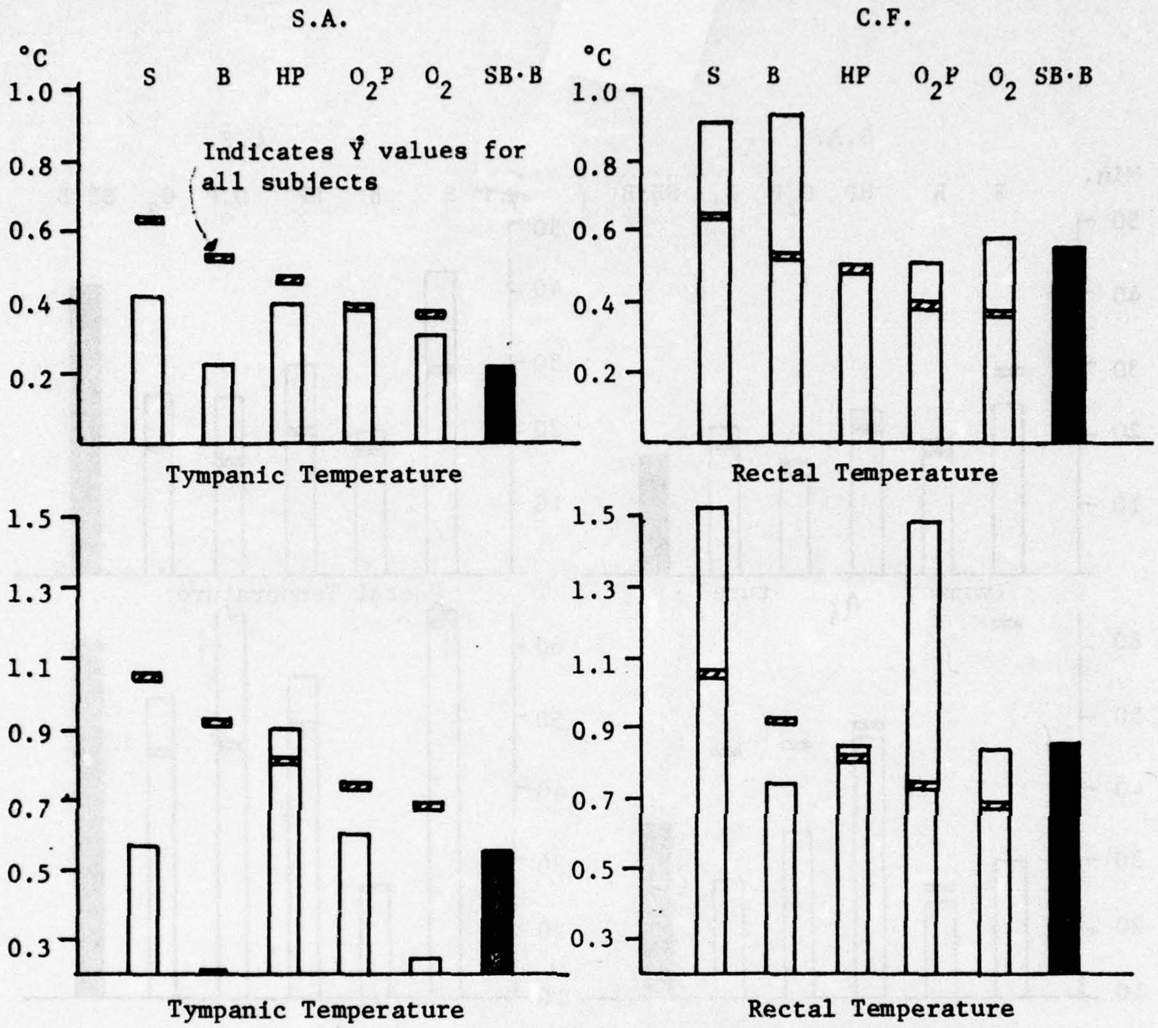

Figure 10. Tympanic and rectal temperature "afterdrops" for two subjects. "Afterdrops" during body to body rewarming in a sleeping bag are displayed along with "afterdrops" associated with the 5 other rewarming modalities.

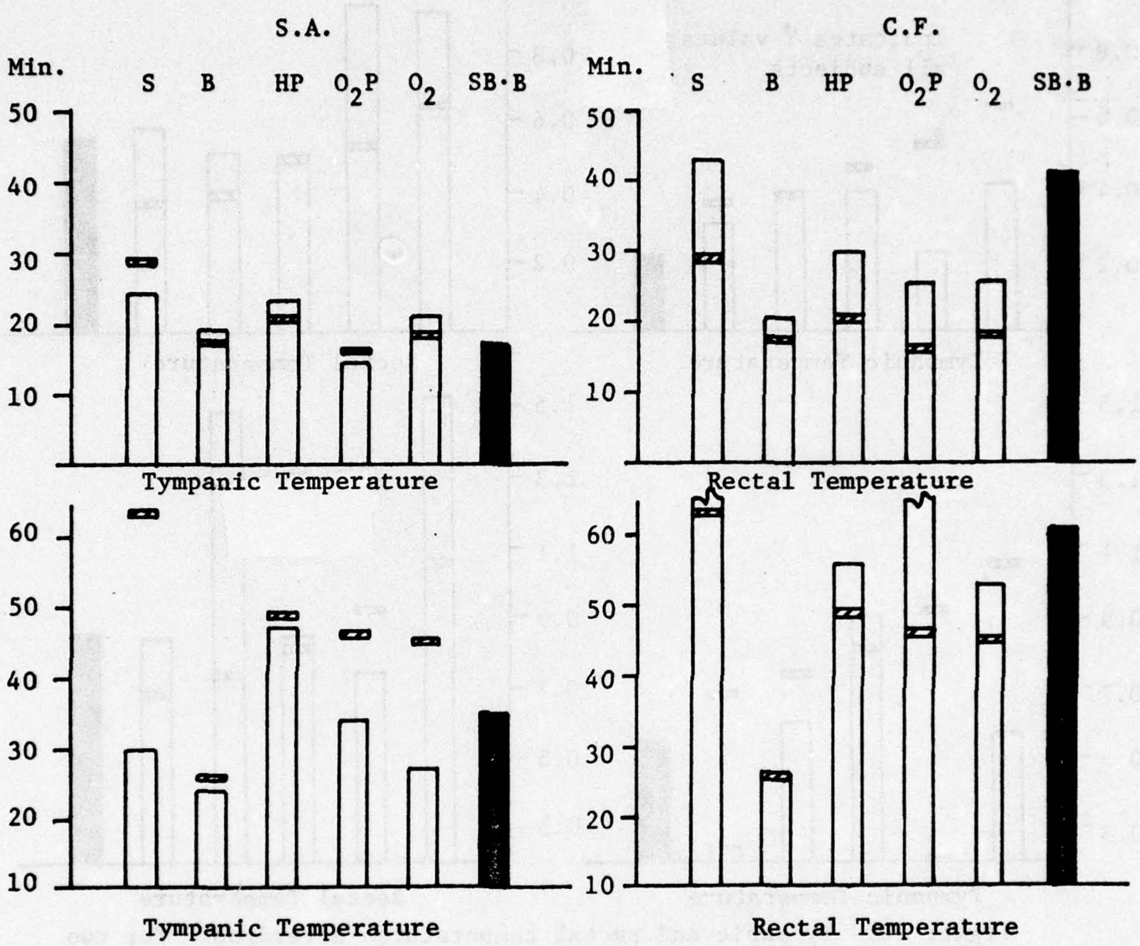

Figure 11. Rectal and tympanic temperature recovery times for two subjects following body to body rewarming in a sleeping bag. Recovery times following other rewarms are displayed for comparative purposes.

DISCUSSION

These results confirm the theoretical expectation that inhalation rewarming can be an effective treatment for hypothermia in humans. A previous study has shown that no significant difference exists in the amount of tympanic and rectal temperature "afterdrop" between inhalation rewarming and rewarming by warm whirlpool bath (13). However, that experiment did not include a control for shivering, and hence it could not estimate the contribution to rewarming of shivering thermogenesis. The present study not only verifies that no significant difference exists in temperature "afterdrops" between inhalation and water bath rewarming, but it also clearly establishes a statistical difference in the absolute amounts of tympanic and rectal temperature "afterdrops" between passive rewarming by shivering and active rewarming through inhalation of heated, saturated oxygen. Further more, inhalation rewarming is associated with a significantly faster recovery time at the tympanic site than that associated with shivering alone. The rectal temperature recovery time for inhalation rewarming is also rapid, but a statistical difference of 0.005 cannot be established from the recovery time associated with shivering thermogenesis alone.

The effectiveness of inhalation of heated, water saturated oxygen in rewarming these mildly hypothermic subjects, as shown both by the small "afterdrops" in tympanic temperature and by the rapid tympanic temperature recovery time, is not due to a direct effect of the heat source on the tympanic membrane. Two previous studies indicated that applications of heat to various areas of the head and neck caused spurious changes in tympanic temperature measurements (26, 27). Our studies do not confirm

this finding, since the normothermic control subjects showed no significant changes in tympanic temperatures while breathing heated, saturated oxygen. Presumably, then, the rewarming responses as measured at the tympanic site reflect real changes in the subjects' "core" temperature.

Inhalation rewarming, is therefore an effective emergency therapy for accidental hypothermia. Peripheral vasodilation is avoided, and hence the hazards of rewarming shock and induction of ventricular fibrillation by cold and acidotic venous return are minimized. With the inhalation method, direct warming of the brain would occur by conduction from the nasopharynx, and by circulation of warmed vertebral and carotid arterial blood. The more rapid rewarming of the brain would both reverse cold-induced depression of the respiratory centers and more rapidly stimulate regaining of consciousness by the severely hypothermic victim. With the inhalation method of rewarming, a rapid delivery of heat to the heart would also be expected. This would occur from direct warming of the endocardium by return of pulmonary venous blood, from coronary arterial warming of the myocardium, and from mediastinal warming of the pericardium. Rapid warming of the heart in this manner would minimize the possibility of ventricular fibrillation and would potentiate increased cardiac output (31, 32). Although previous studies have doubted the capacity of the inhalation technique to deliver sufficient calories to rewarm a hypothermic subject (17), the results of this experiment and the results of experiments on hypothermic dogs (16) demonstrate that "core" temperatures can indeed be increased with this method.

A further advantage of inhalation rewarming with heated, saturated oxygen can be anticipated. Since the oxygen supply to the myocardium is

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decreased in hypothermia, both from decreased coronary vascular flow (14) and decreased oxyhemoglobin dissociation (4), the possibility of ventricular fibrillation from a limitation of myocardial energetics is enhanced (15). The inhalation of heated oxygen in the treatment of hypothermia would not only be therapeutic in terms of warming of the myocardium, but also from a concurrent increase in coronary arterial oxygenation.

The failure of any of the peripheral rewarming techniques (water bath, heating pads, and heating pads plus inhalation) to provide significantly smaller tympanic or rectal temperature "afterdrops" than those found in the shivering controls was somewhat surprising. These methods of aggressive hypothermia therapy might properly be expected to provide more effective rewarming than that found in passive shivering alone. Two hypotheses to explain these results are offered. First, as is well known, peripheral rewarming is usually associated with some degree of peripheral vasodilation and subsequent "paradoxical" central cooling. The return to the "core" of relatively cold peripheral blood, potentiated by vasodilation, results in a further drop in the central body temperature. Each of the techniques of peripheral rewarming used in this experiment, then, presumably was associated with peripheral vasodilation and subsequent continued declines in the tympanic and rectal temperatures; whereas the control rewarming by passive shivering thermogenesis was not accompanied by a large degree of peripheral vasodilation, and the body's vasoconstricted, insulative shell was maintained. Secondly, the magnitude of shivering accompanying each of the active peripheral rewarming methods was subjectively less than that found with passive rewarming alone. Although no metabolic or electromyographic measurements were performed during this study, the

subjects reported that their shivering was greatest when no additional means of rewarming was used. This implies that the physiologic capability of the mildly hypothermic subject to rewarm himself through shivering thermogenesis is impeded by certain types of active peripheral rewarming. The subjects in this study were, by and large, well muscled individuals whose shivering thermogenic capacity was relatively large. Any inhibition of the subjects' shivering, then, would be expected to increase tympanic and rectal temperature "afterdrops" and to slow recovery times. If the magnitude of heat delivered during treatment with a peripheral rewarming technique approximated the amount of potential calories lost through inhibition of shivering thermogenesis, then no significant difference in the efficacy of therapy would be expected between passive shivering and active peripheral rewarming. This was, in fact, the result in this experiment.

Recent studies by Hayward et al (12) have clearly demonstrated that thermoregulatory heat production in man depends quantitatively upon interaction of signals from peripheral and central receptors. In studies on hypothermic volunteers under conditions essentially identical to those used in this experiment, an abrupt cessation to shivering was found in subjects immersed in warm water baths, when the skin temperature was rewarmed to approximately 33°C. This occurred at a time when the core temperatures were at their lowest levels. In the present rewarming study, our subjects showed a similar cessation of shivering and experienced a subjective feeling of warmth during peripheral rewarming treatments, even while their rectal and tympanic temperatures were at, or below 35°C. The inhibition of shivering by peripheral rewarming in these mildly hypothermic subjects, then, explains why the heating pads were not significantly better than shivering alone. It also explains why the

addition of heating pads to the inhalation of heated, saturated oxygen reversed the advantages of the latter method's central warming effect. The heating pads apparently warmed a sufficient area of skin so as to inhibit, at the central nervous system level, the caloric contribution of shivering thermogenesis. At the same time, the pads did not deliver sufficient calories to significantly alter the tympanic or rectal temperature "afterdrop" over that seen in the control. The same effect was observed for the warm whirlpool bath. The rapid peripheral rewarming of the skin in a water bath effectively shut off shivering in a short period of time, while simultaneously creating a large component of peripheral vasodilation. These two effects combined to yield relatively large tympanic and rectal temperature "afterdrops". However, the capacity of the water bath to deliver heat to the body is great, and hence the tympanic and rectal temperature recovery times for this method of rewarming were short.

Conclusive comments cannot be made on the effectiveness of rewarming by body to body contact with normothermic subjects. Since only two subjects were rewarmed in this manner, statistical statements regarding comparison with the five other methods of rewarming examined are inappropriate. However, it should be noted that in both subjects the "afterdrops" of tympanic and rectal temperatures were smaller with this technique than with shivering alone. In fact, in one of the subjects (C.F.), who had a very large rectal temperature "afterdrop" during the shivering control, body to body rewarming yielded rectal and tympanic temperature "afterdrops" comparable to the small changes found during inhalation rewarming. Hence, peripheral rewarming by body to body contact with normothermic persons may prove to be an effective first-aid treatment, but further experimental studies are needed to verify this fact. The technique should certainly be used if no other means of active rewarming are available.

The pattern of temperature response at the tympanic and rectal sites supports the contention that inhalation of heated, water saturated O_2 leads to the uptake of calories by the alveoli. Warm aortic blood produces a rapid tympanic membrane response while the rectal response is slower due to its more distal location.

Finally, it should be emphasized that in these experiments we were examining the efficacy of various rewarming methods on healthy, muscular, vigorously shivering, mildly hypothermic subjects. Subject safety did not permit lowering the body temperature until shivering gave way to muscular rigidity. Therefore, in many instances, the experimental subjects would differ from the significantly hypothermic accident victim requiring emergency medical treatment. The moderate to severely hypothermic victim is not effectively shivering, and he is usually unconscious. *Frequently he is also* in poor health. Hence the statements regarding inhibition of shivering by peripheral rewarming in the experimental subjects, do not apply to this type of hypothermic emergency patient.

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RECOMMENDATIONS

The results of this study indicate that the first-aid treatment of hypothermia should be centered around inhalation rewarming as a first choice. Search and rescue units who operate in cold air or water environments should be provided with the necessary training and equipment to provide effective inhalation rewarming therapy.

Where peripheral rewarming is used, in isolation or in combination with a method of core rewarming, heat application should be restricted to the areas of high heat transfer (head, neck, trunk and groin). This can be accomplished in many ways, using heating pads, water baths, hot wet towels or chemical hot packs. However, if possible the patient's limbs should not be actively rewarmed.

A detailed description of the treatment of hypothermia is provided in Appendix A.

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APPENDIX A

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Recommended Revisions of COMDTINST 3130.15B

Subject; Hypothermia; recognition of and precautions for

1. Purpose. This instruction describes the symptoms of hypothermia (abnormal lowering of internal body temperature) and prescribes precautions and treatment for the condition.

2. Cancellation. Commandant Instruction 3130.15B

3. Background. Survivors of maritime disasters frequently suffer from the condition of hypothermia in addition to a variety of injuries, exposure and shock. General body hypothermia is the leading cause of death among survivors of shipwreck and other catastrophes at sea. If not recognized and treated promptly, hypothermia can rapidly turn a survivor into a fatality. During, and subsequent to, rescue operations, a survivor in a critical hypothermia condition may suffer a fatal further loss of body temperature due to physical exertion or delay in taking immediate positive measures to restore body heat. A struggling survivor trying to aid in his own rescue may drive his body temperature down below the point where unconsciousness and/or death results. A survivor removed from the water and left untreated may suffer a further critical loss in body temperature, bringing on death after rescue. It should be noted that survivors in relatively "warm" water can also suffer from hypothermia if exposed long enough. Also the condition can be brought on by exposure to cold air temperatures, especially if accompanied by wind, when adequate protective clothing is not worn.

4. Symptoms of Hypothermia.

a. Body Temperature. The most useful yardstick in identifying hypothermia, determining need for treatment and evaluating the victim's chance of survival, is his body temperature. The hypothermia victim has a core temperature which is lower than normal. It is emphasized that only core temperatures are relevant. This means that oral temperatures cannot be used, and rectal temperatures must be obtained from a site at least 10 to 15 cm beyond the anus. Enclosure (1) depicts the relationship between core temperature and hypothermia symptoms.

b. Blood Pressure. Blood pressure is lower than normal. It is frequently less than 100 mm Hg. systolic.

c. Pulse. The pulse is generally slow and often irregular. It may be difficult to locate in the extremities because of blood vessel constriction. In this case the best location for measuring the heart rate is in the neck at the carotid arteries, or in the groin at the femeral arteries.

d. Level of Consciousness. Individuals suffering from hypothermia often have alterations in their level of consciousness. As the core temperature decreases to 90°F, the consciousness becomes progressively more clouded. Loss of consciousness occurs between 86-90°F.

e. Respiratory Rate. Respiration is initially increased in the early stages of hypothermia. But as the core temperature falls below 92°F, the respiratory rate gradually diminishes. At low core temperatures, respiration is very slow and often labored.

f. Shivering. Shivering is a reflex mechanism used by the body to produce heat. It becomes increasingly vigorous and uncontrollable near core temperatures of 95°F, but it steadily diminishes between 90-95°F. Shivering is replaced by muscular rigidity between 86-90°F.

g. General Appearance. The hypothermia victim is pale in appearance and his skin is very cold to the touch. In fact, his skin and subcutaneous tissues are often at the immersion water temperature. The victim's pupils begin to dilate at core temperatures near 92°F, and are fully dilated and poorly reactive to light at around 86°F.

h. When a low reading rectal thermometer of sufficient length to obtain a true core temperature (10-15 cm beyond the anus) is not available, a rough estimation of the victim's temperature can be made as follows:

(1) above 95°F: The victim is conscious, alert and may have vigorous shivering.

(2) 90-95°F: The victim is conscious, but he has a mild to moderate clouding of his mental faculties. Shivering is present, but diminished.

(3) 86-90°F: The victim has severe clouding of his consciousness, or he may be unconscious. Shivering is replaced by muscular rigidity.

(4) below 86°F: The victim is unconscious, with diminishing respirations.

(5) below 80°F: The victim has barely detectable or non-detectable respiration.

5. Precautions During Rescue. If, due to the air or water temperature, or the length of time a survivor has been exposed, critical hypothermia is suspected, rescue attempts should be made in such a manner as to minimize the amount of exertion by the survivor. This point must be emphasized. Even small amounts of physical activity by the hypothermic victim often leads to large amounts of heat loss, and possibly fatal further drops in core temperature. It may be necessary for the rescuer suitably clothed, to enter the water and assist the survivor into the rescue device. At all times the victim must be handled as gently as possible. Excessive movement can precipitate fatal heart beat irregularities.

6. Treatment of Hypothermia. Emergency treatment should begin as soon as possible. It must be remembered that the body temperature continues to fall even though the victim is no longer exposed to the cold water or air. (Evacuation to a medical facility should be accomplished after or during emergency treatment.)

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a. Remove Wet Clothing. If the patient's body temperature is 95°F or above, no other treatment is necessary than dry clothing in a warm environment. If the patient cannot be removed to a warmed compartment with blankets, dry clothing or warming method, the wet clothing should not be removed. Under these circumstances, wet clothing is better than no clothing. Remember that if the victim's clothing is removed, it should be accomplished as gently as possible, with a minimum of body manipulation. If the victim is to be hoisted by rescue helicopter from a boat, both his head and body should be wrapped in blankets prior to the hoist. This prevents a further heat loss caused by the wind-chill effect of the helicopter's rotor wash.

b. Warm Rapidly. Do not burn or overheat. The following warming methods are recommended. They are listed in order of preference according to available facilities.

(1) If available, administer heated, humidified oxygen to the victim, at an inhalation temperature of 110-115°F. This will rapidly supply heat to the heart and brain, and it will protect against further temperature drops in these vital organs. The heated oxygen should be continued throughout the rewarming period, and should be used in conjunction with the other suggested rewarming procedures.

(2) Water bath. Bath temperatures must be over 100°F but not greater than 115°F. A temperature of 110°F is recommended. If a tub is not available, an inflated life raft can be used as a tub. Place the patient's trunk in the bath with his limbs out of the water. At the same time, wrap a towel or other piece of clothing soaked in the warm water around the patient's head and neck. Be sure to continually rewet the head and neck covering during rewarming. If the patient has major injuries in addition to hypothermia, or if cardio-pulmonary resuscitation is necessary, do not use the water bath rewarming method. Furthermore, if the victim has been hypothermic for twelve hours or more, this method again should not be used (see paragraph 4 (e), below).

(3) Apply hot, wet towels, blankets or other clothing at 115°F to the patient's head, neck, trunk, and groin. These are areas of high heat transference, and they will efficiently deliver heat to the patient's core. This can best be accomplished by wrapping the victim in a warm, wet blanket, covering the areas mentioned, and leaving the arms and legs free. Hot water can then be periodically poured over the blanket to keep it at the proper temperature. If hot water is not available, heating pads or chemical hot packs can be applied to the same areas.

(4) Apply body warmth by direct contact with a member of the rescue team. The rescuer should remove his clothing and ensure as much body contact with the victim as possible. Both rescuer and victim should then be wrapped in a blanket or sleeping bag to conserve the rescuer's body heat.

c. Observe Respiration Closely and Remove any Secretions. If a suction unit is available, a catheter suction of the trachea is advisable if breathing is impaired. If oxygen is not available, mouth-to-mouth resuscitation may be necessary. This should be done at a reduced rate, however, since the hypothermia victim has a decreased metabolic rate.

d. Give Nothing Orally. Watch for vomiting and the possibility of aspiration (taking into the lungs) of vomitus. Alcohol is absolutely forbidden in deep hypothermia.

e. Treat for Shock. Be aware that patients who have been hypothermic for long periods may experience dangerous falls in blood pressure during rewarming. For this reason these patients should be kept lying on their back with their legs slightly elevated and their head slightly lowered. Long-term hypothermia victims (in whom hypothermia has developed over twelve hours or more) should not be rewarmed in a water bath; the combination of a fall in blood pressure with elevation of the head may cause a serious compromise in the blood supply to the brain.

f. Additional Treatment by Medical Personnel. When trained medical personnel are available and have the necessary facilities, the following additional treatment is recommended:

(1) Administer warmed 5% dextrose in lactated Ringer's solution at a rate sufficient to bring systolic blood pressure to 100 mm Hg. If the patient is not producing urine, fluid administration should be closely controlled so as to avoid volume overload of the hypothermic myocardium. An indwelling bladder catheter to monitor urine output and a central venous pressure monitor are advised.

(2) Monitor arterial blood gases and pH, and treat acidosis as indicated with intravenous sodium bicarbonate.

(3) If the patient is not ventilating well, or has any degree of airway obstruction, he should be intubated. Remember, however, that intubation can precipitate ventricular fibrillation in the cold myocardium. To minimize this possibility, the patient should be pre-oxygenated for several minutes with heated, humidified oxygen, if available, or standard oxygen otherwise. Intubation should then be performed under continuous ECG monitoring.

(4) Anti-arrhythmic drugs should not be given as they have little value and may even precipitate ventricular fibrillation.

7. Action. Commanding officers and officers-in-charge shall:

a. Ensure that personnel under their commands are familiar with the contents of this instruction. During the course of routine training, time should be devoted to recognizing hypothermia and minimizing its effects.

b. Ensure that rescue equipment carried by boats and helicopters assigned, includes blankets, oxygen, and if available, an oxygen warming appartus.

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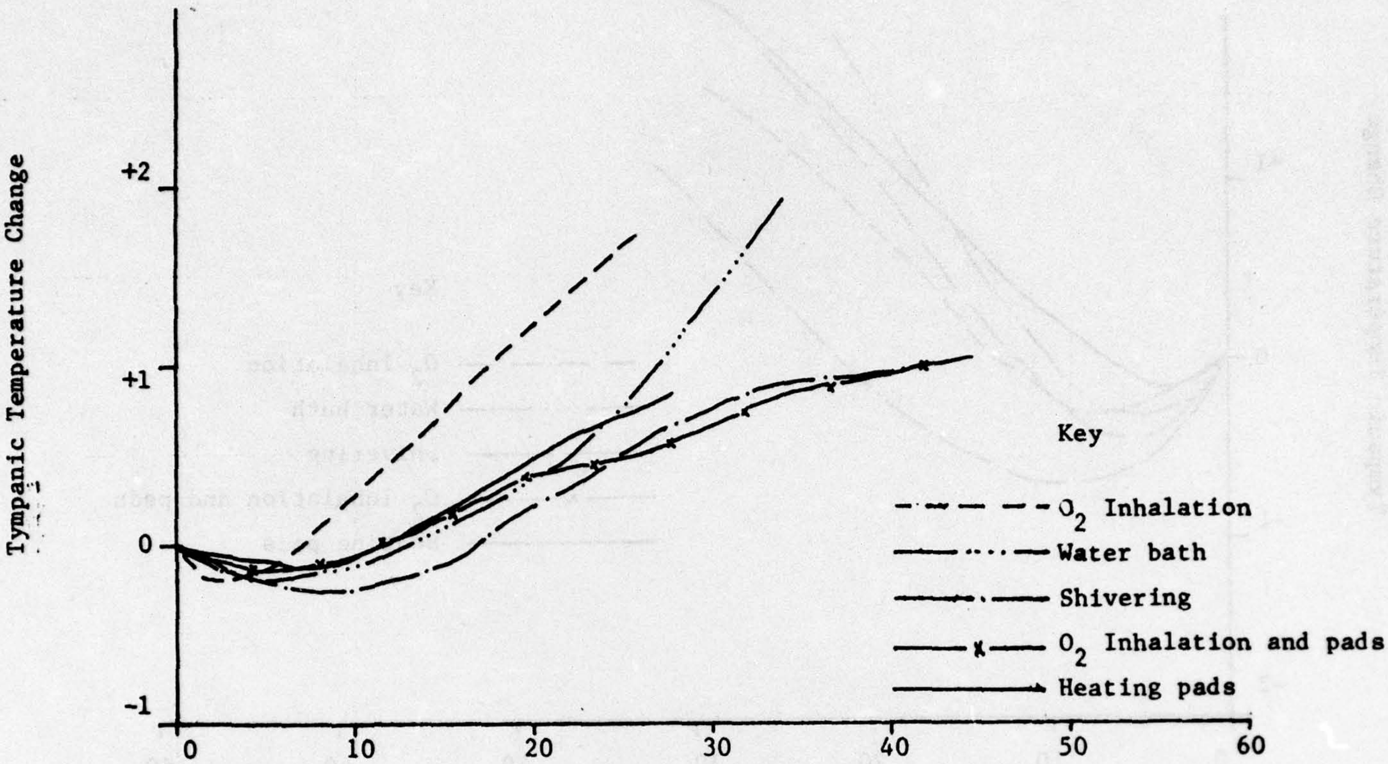
APPENDIX B

Core Temperatures in Relation to Hypothermia Symptoms

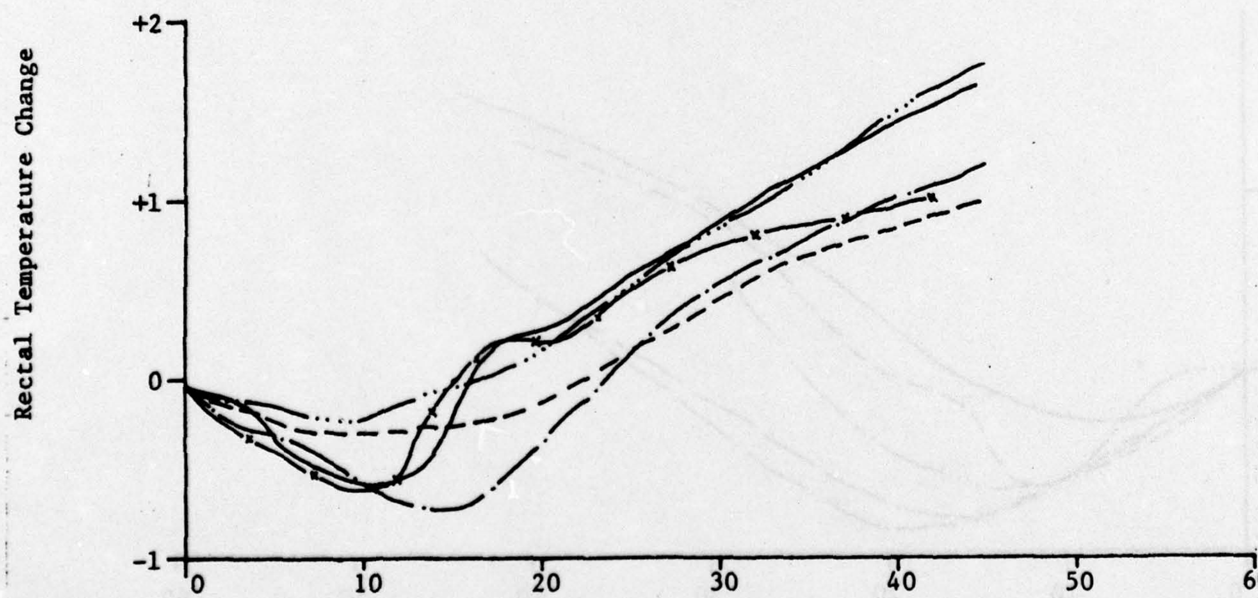
F	C	
100.4	38	
98.6	37	
96.8	36	
95.0	35	Hyperventilation and vigorous shivering
93.2	34	
91.4	33	Clouded consciousness, diminished respiratory rate, and diminished shivering
89.6	32	
87.8	31	Muscle rigidity and loss of consciousness
86.0	30	
85.2	29	
82.4	28	
80.6	27	Cardiac arrythmias occur (irregular heart beat)
78.8	26	
77.0	25	
75.2	24	
73.4	23	Ventricular fibrillation usually the final event
71.6	22	

APPENDIX C

G.M.



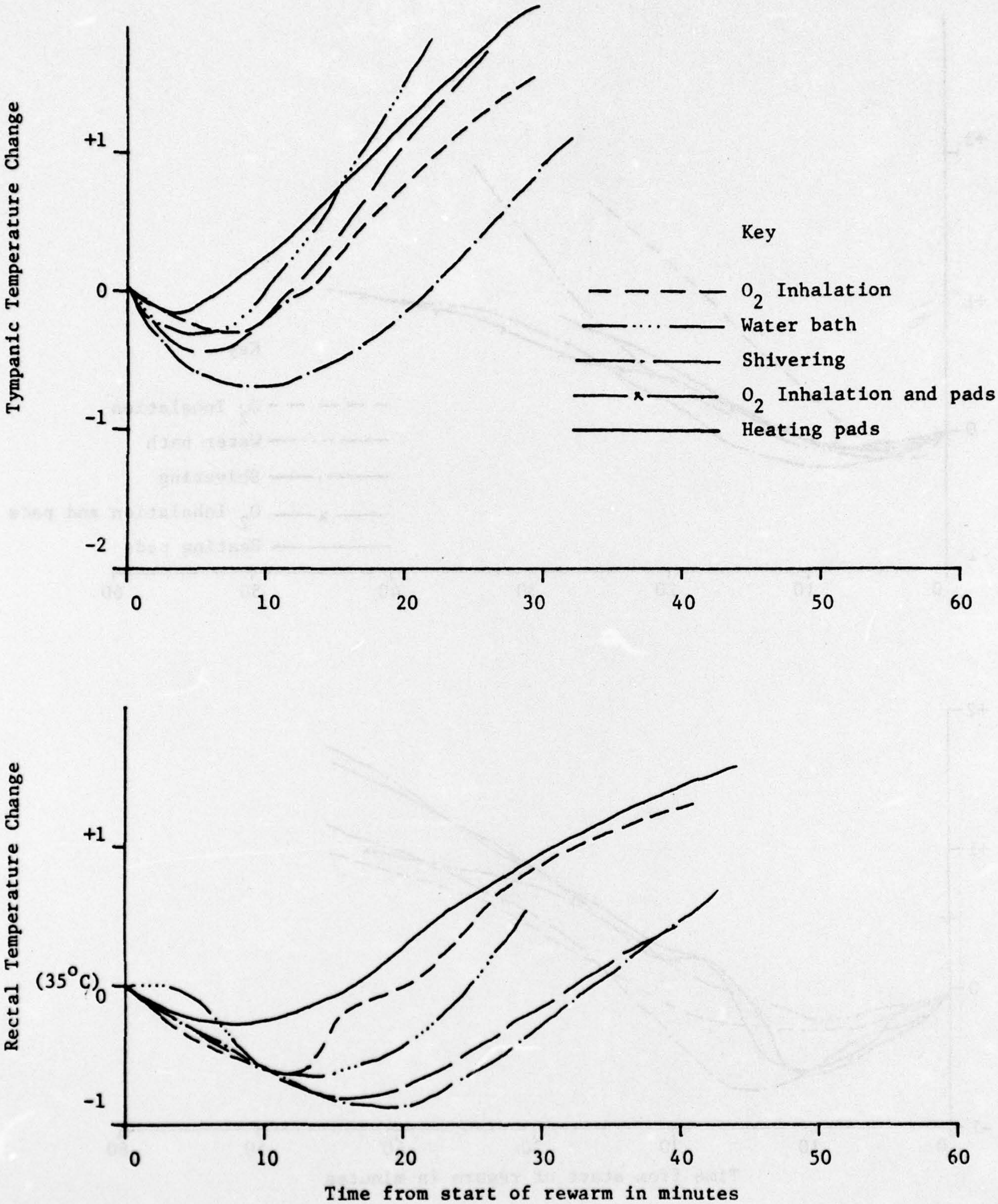
Tympanic Temperature Change
+2
+1
0
-1
0
10
20
30
40
50
60
Key
O_2 Inhalation
Water bath
Shivering
O_2 Inhalation and pads
Heating pads



Rectal Temperature Change
+2
+1
0
-1
0
10
20
30
40
50
60
Time from start of rewarm in minutes

55

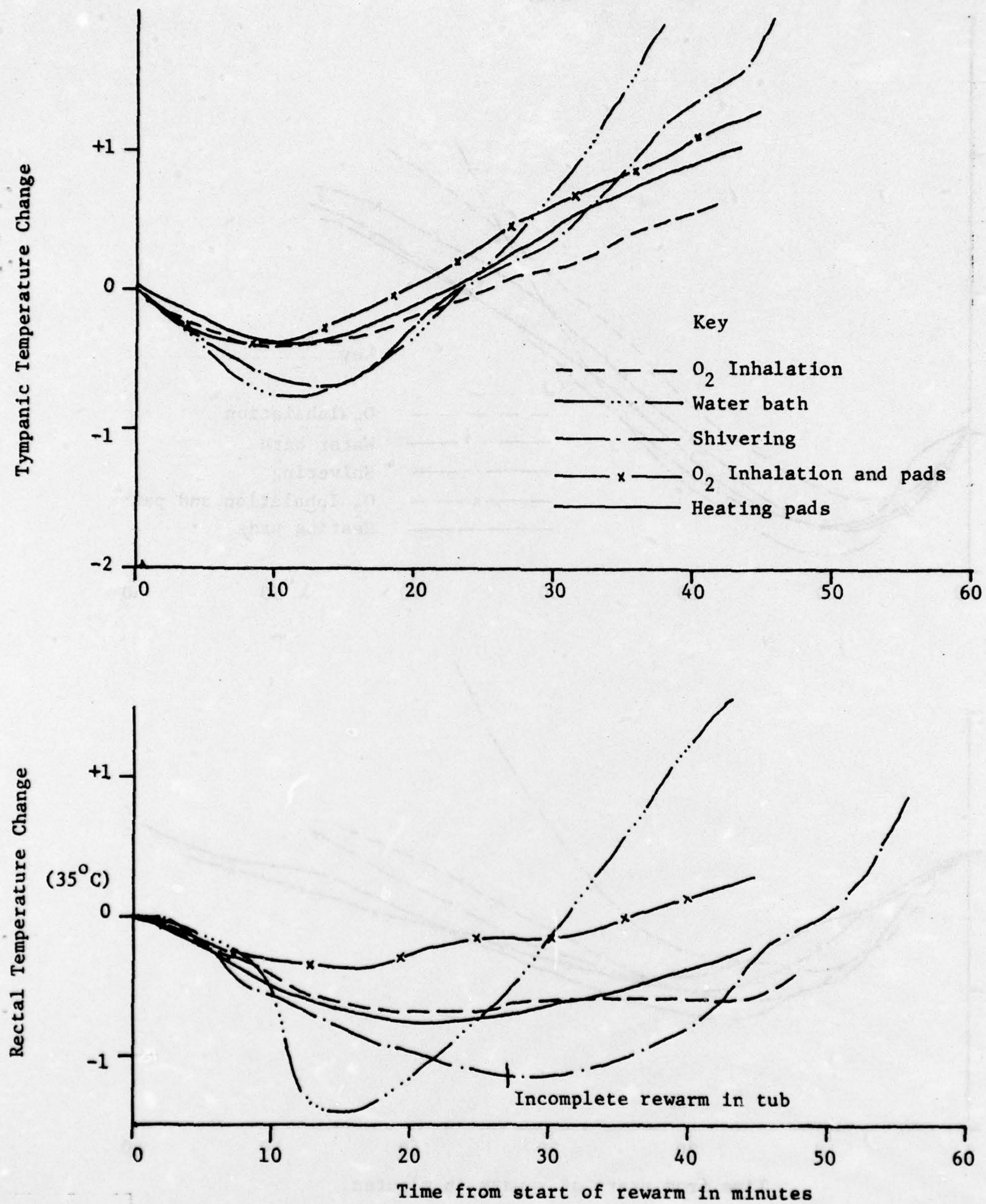
B.L.


Tympanic Temperature Change
+1
0
-1
-2
0
10
20
30
40
50
60
Key
O_2 Inhalation
Water bath
Shivering
O_2 Inhalation and pads
Heating pads
Rectal Temperature Change
+1
(35^oC) 0
-1
0
10
20
30
40
50
60
Time from start of rewarm in minutes

56

3

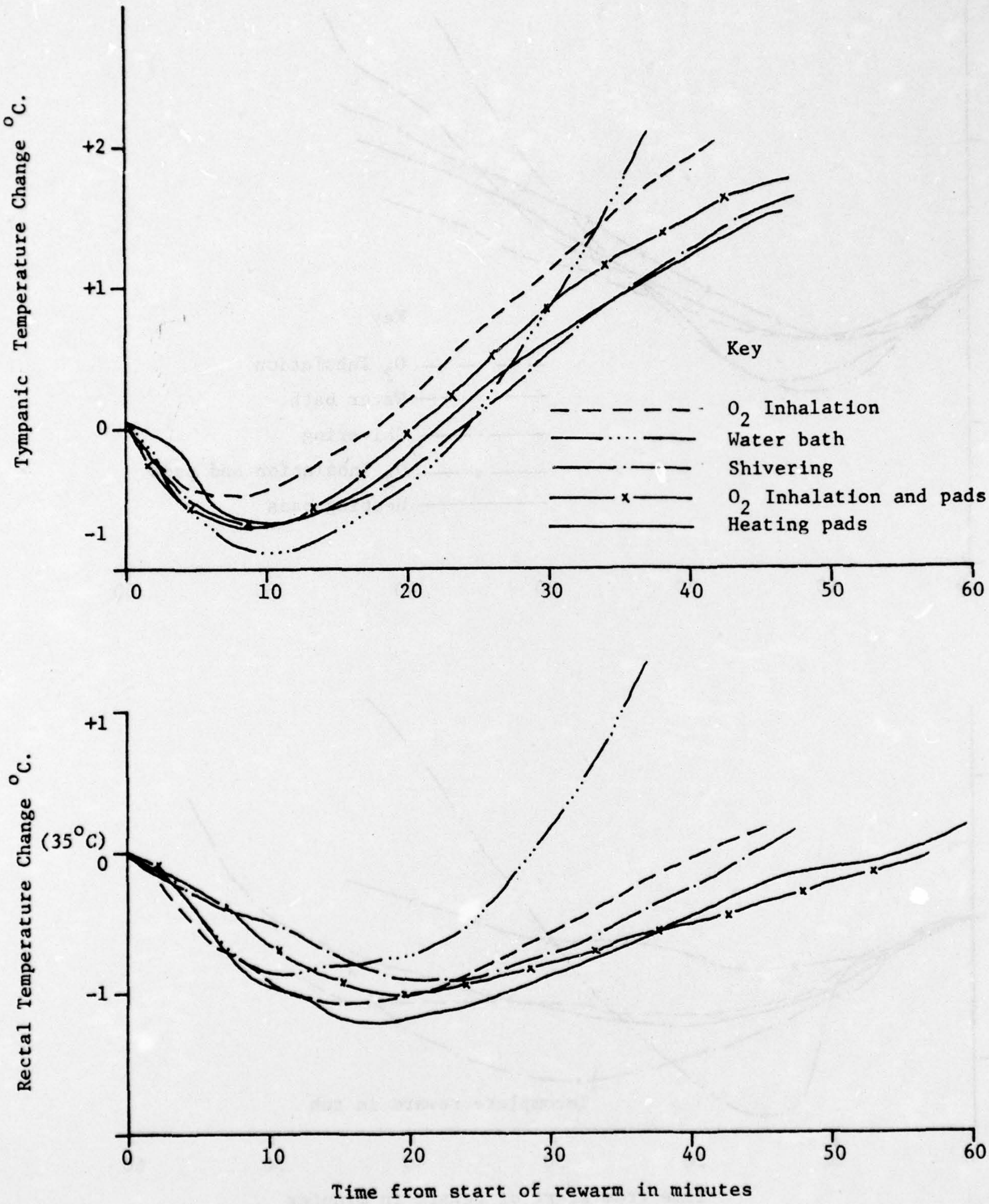
T.A.



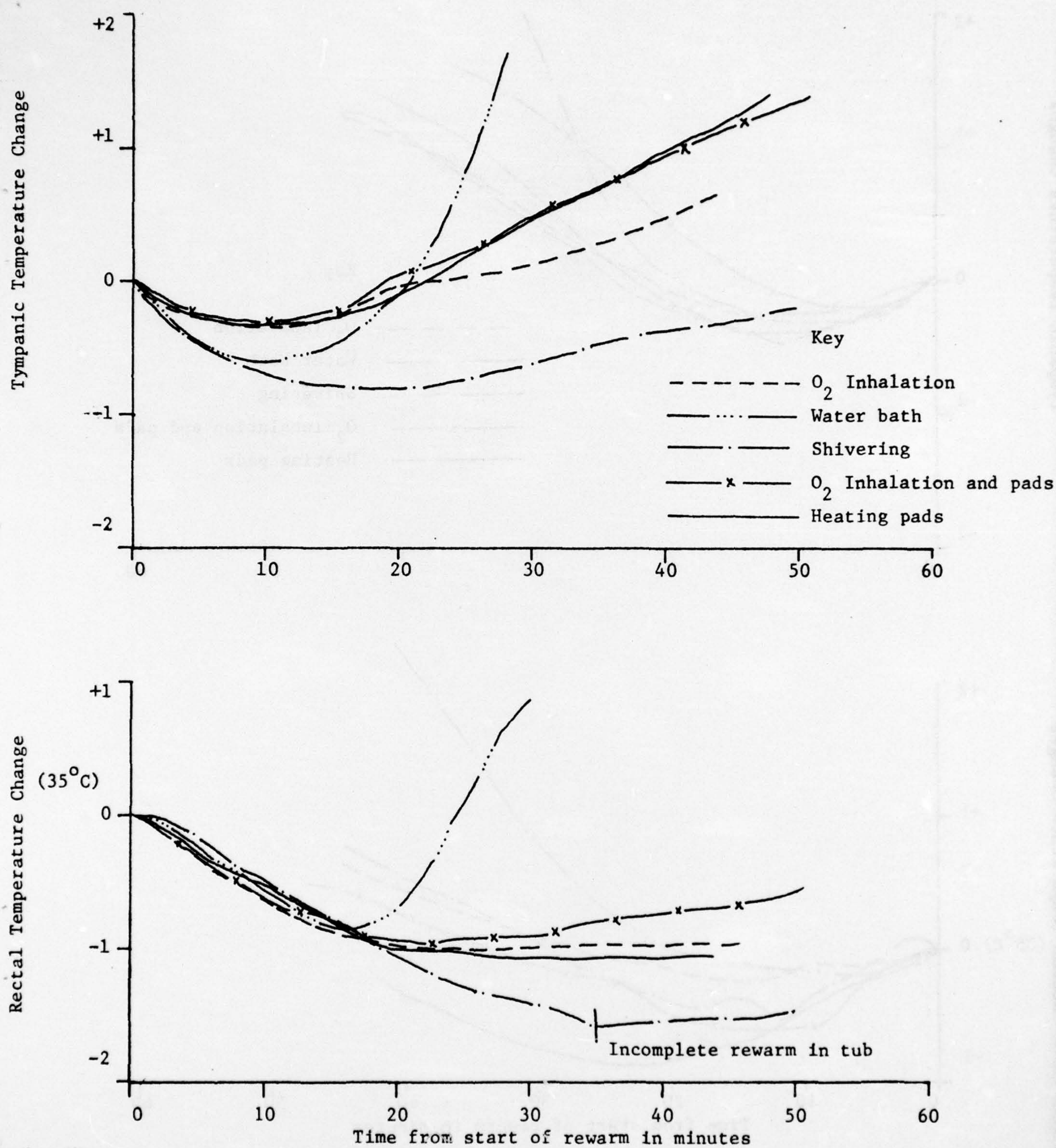
Tympanic Temperature Change
+1
0
-1
-2
0
10
20
30
40
50
60
Key
O_2 Inhalation
Water bath
Shivering
O_2 Inhalation and pads
Heating pads
Rectal Temperature Change
(35°C)
+1
0
-1
Incomplete rewarm in tub
0
10
20
30
40
50
60
Time from start of rewarm in minutes

52

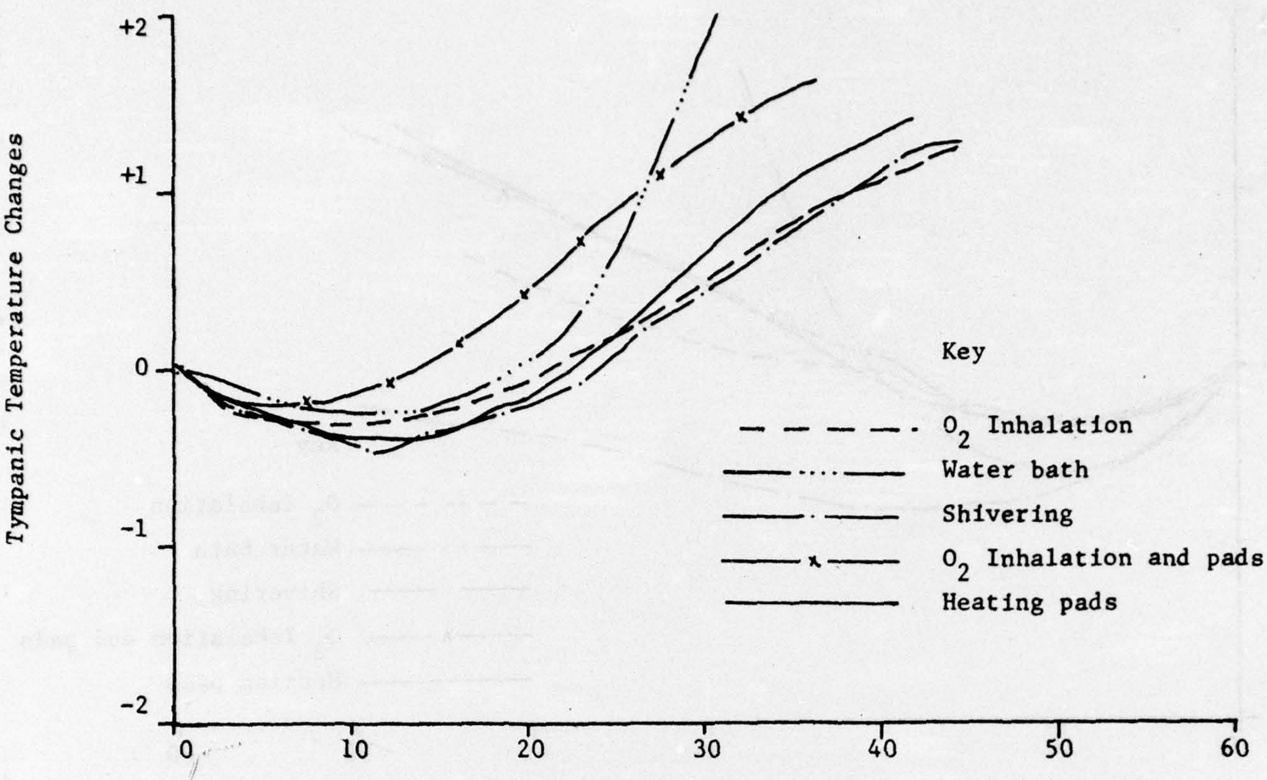
W.R.


Tympanic Temperature Change °C.
+2
+1
0
-1
0
10
20
30
40
50
60
Key
O_2 Inhalation
Water bath
Shivering
O_2 Inhalation and pads
Heating pads
Rectal Temperature Change °C.
+1
(35°C)
0
-1
0
10
20
30
40
50
60
Time from start of rewarm in minutes

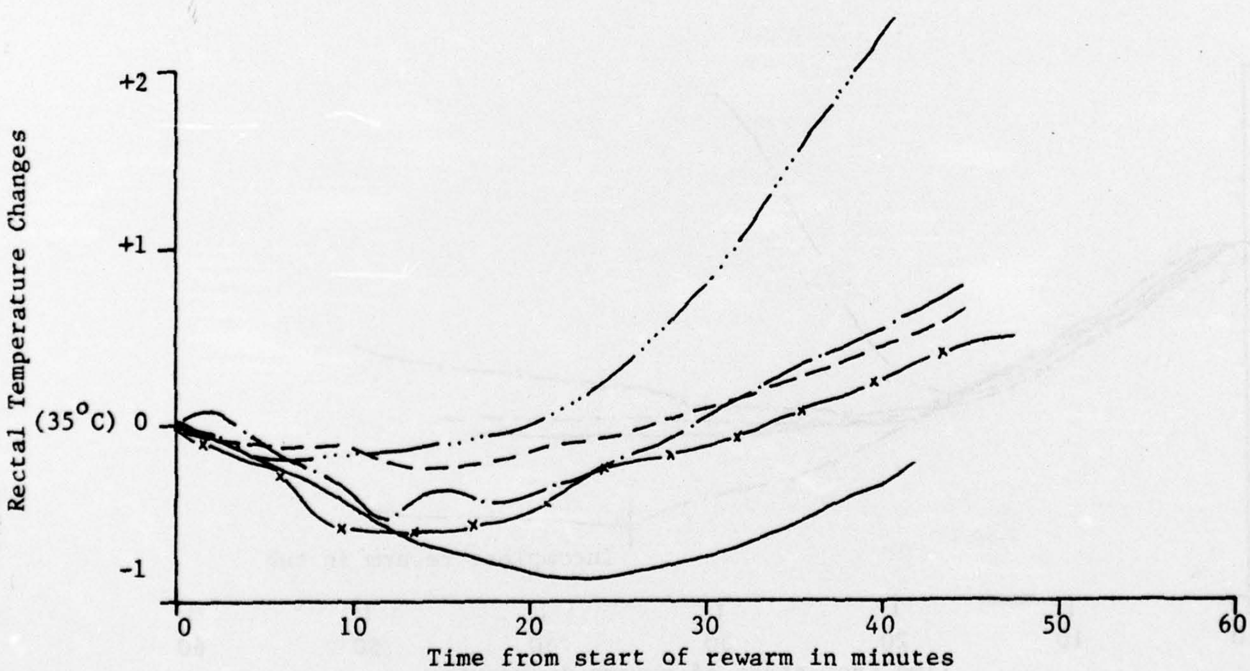
M.C.


Tympanic Temperature Change
+2
+1
0
-1
-2
0
10
20
30
40
50
60
Key
O2 Inhalation
Water bath
Shivering
O2 Inhalation and pads
Heating pads
Rectal Temperature Change
(35°C)
+1
0
-1
-2
Incomplete rewarm in tub
Time from start of rewarm in minutes

S.A.



+2
+1
0
-1
-2
Tympanic Temperature Changes
0
10
20
30
40
50
60
Key
O_2 Inhalation
Water bath
Shivering
O_2 Inhalation and pads
Heating pads

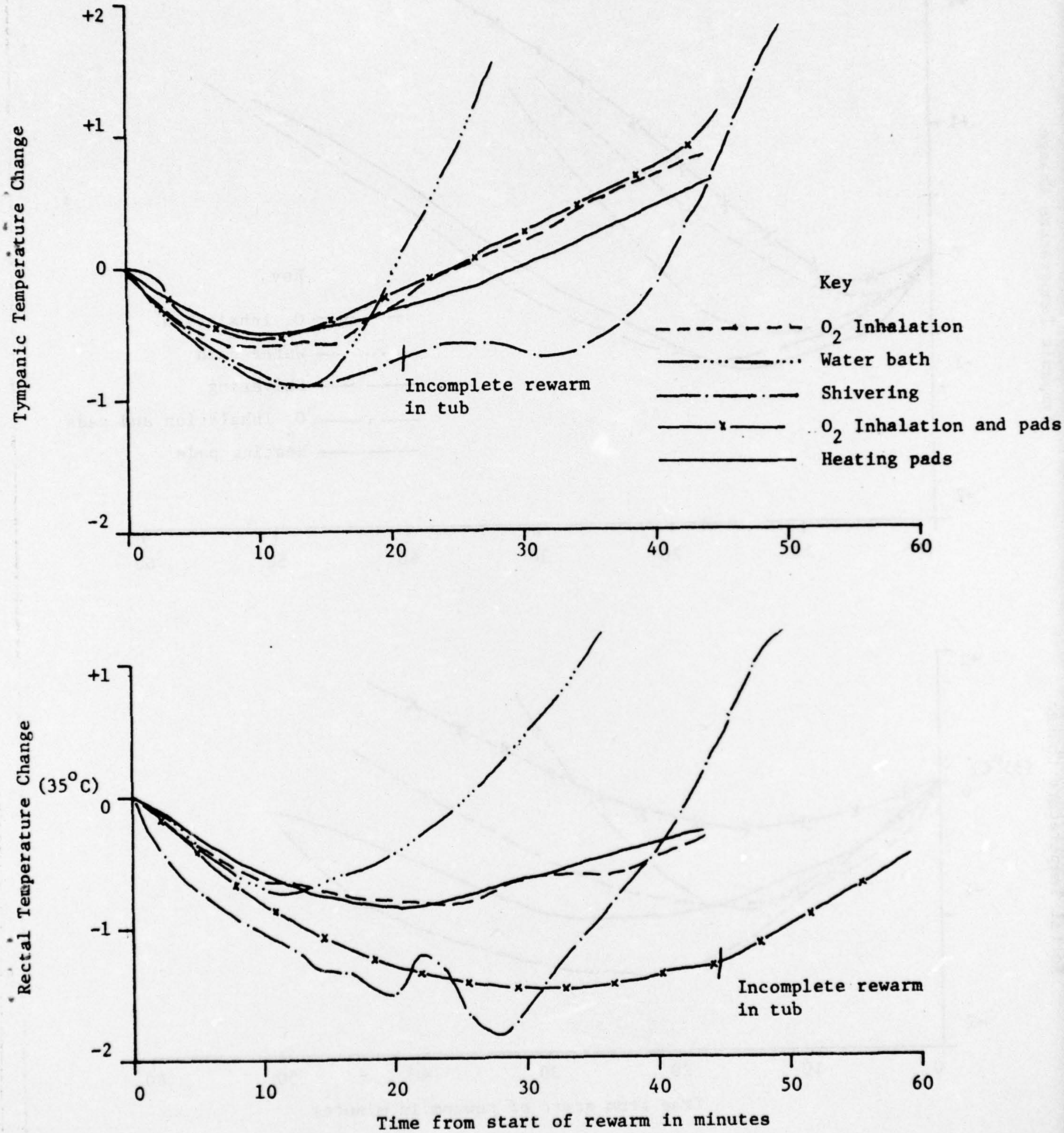


+2
+1
(35°C) 0
-1
Rectal Temperature Changes
0
10
20
30
40
50
60
Time from start of rewarm in minutes

60

9

C.F.

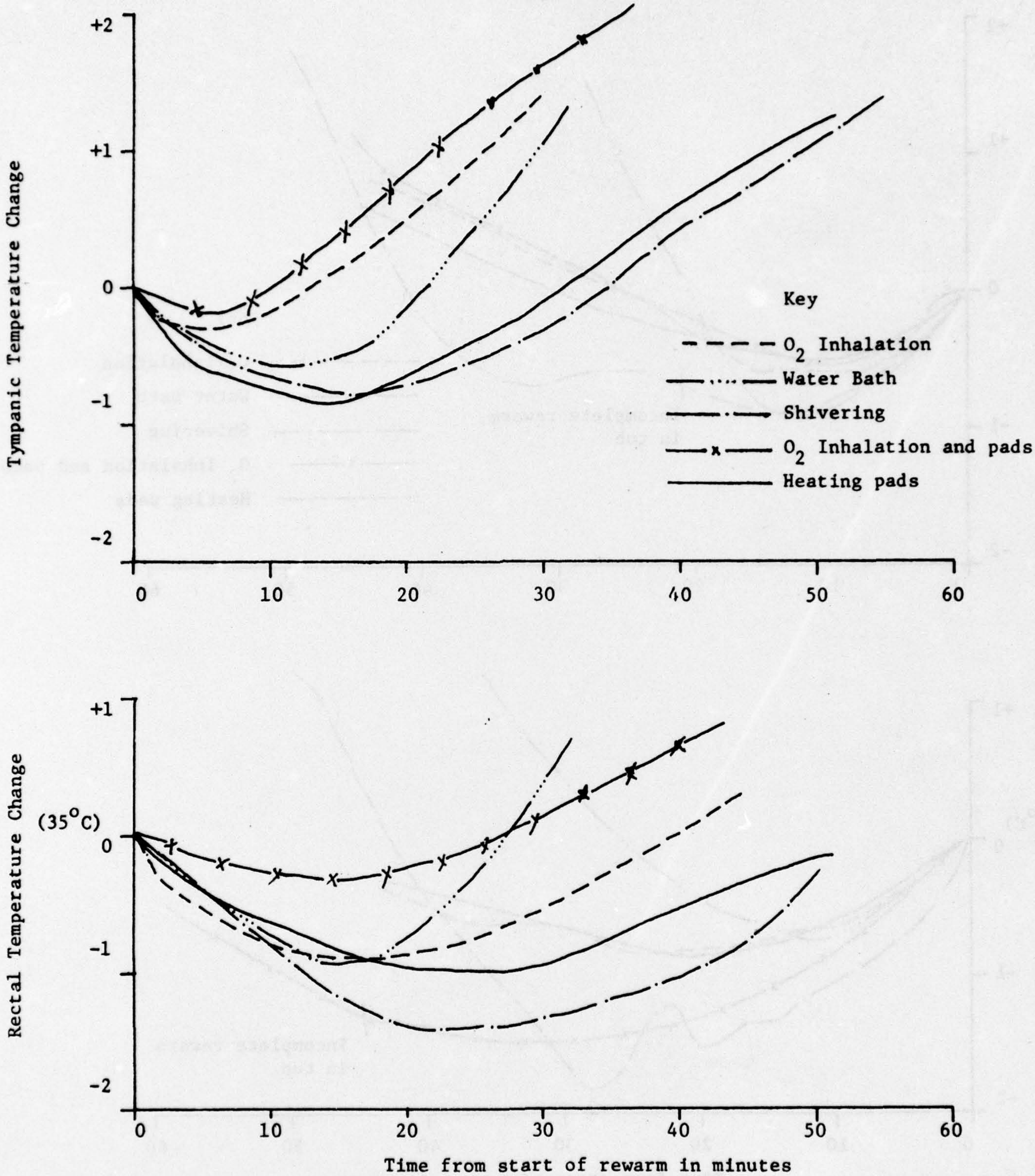


Tympanic Temperature Change
+2
+1
0
-1
-2
0
10
20
30
40
50
60
Incomplete rewarm in tub
Key
O_2 Inhalation
Water bath
Shivering
O_2 Inhalation and pads
Heating pads
Rectal Temperature Change
(35^oC)
+1
0
-1
-2
0
10
20
30
40
50
60
Incomplete rewarm in tub
Time from start of rewarm in minutes

61

10

J.M.


Tympanic Temperature Change
+2
+1
0
-1
-2
0
10
20
30
40
50
60
Key
O_2 Inhalation
Water Bath
Shivering
O_2 Inhalation and pads
Heating pads
Rectal Temperature Change
(35°C)
+1
0
-1
-2
0
10
20
30
40
50
60
Time from start of rewarm in minutes

62